



SEMI-ANNUAL REPORT

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OCEAN OBSERVATIONS WITH EOS/MODIS:

Algorithm Development and Post Launch Studies

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Preamble

As in earlier reports, we will continue to break our effort into seven distinct units:

- Atmospheric Correction Algorithm Development
- Whitecap Correction Algorithm
- In-water Radiance Distribution
- Residual Instrument Polarization
- Pre-launch/Post-launch Atmospheric Correction Validation
- Detached Coccolith Algorithm and Post-launch Studies

This separation has been logical thus far; however, as launch of AM-1 approaches, it must be recognized that many of these activities will shift emphasis from algorithm development to validation. For example, the second, third, and fifth bullets will become almost totally validation-focussed activities in the post-launch era, providing the core of our experimental validation effort. Work under the first bullet will continue into the post-launch time frame, but will be driven in part by algorithm deficiencies revealed as a result of validation activities. We will continue to use this format for CY97.

Abstract

Several significant accomplishments were made during the present reporting period.

- We expanded our new method, for identifying the presence of absorbing aerosols and simultaneously performing atmospheric correction, to the point where it could be added as a subroutine to the MODIS water-leaving radiance algorithm.
- We successfully acquired micro pulse lidar (MPL) data at sea during a cruise in February.
- We developed a water-leaving radiance algorithm module for an approximate correction of the MODIS instrument polarization sensitivity.
- We delivered a complete version of the water-leaving radiance algorithm to R. Evans for incorporation into the next version of MODIS software.
- We participated in one cruise to the Gulf of Maine, a well known region for mesoscale coccolithophore blooms. We measured coccolithophore abundance, production and optical properties.

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1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1997 there are seven objectives under this task. Task (i) below is considered to be the most critical. If the work planned under this task is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral matching" algorithm with the goal of having an algorithm ready for implementation by the end of CY 1997. As our work has shown that a knowledge of the vertical distribution of the aerosol is critical, if it is strongly absorbing, we have procured a micro pulse lidar (MPL) system for use at sea on validation cruises, and from islands (likely Barbados or the Canary Islands) in the Saharan dust zone, to begin to compile the climatology of the vertical distribution required to adopt candidate distributions for use in this region.

(ii) We need to test the basic atmospheric correction algorithm with actual ocean color imagery. We will do this by looking at SeaWiFS and OCTS imagery as they become available.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. However, in the light of the success of our spectral matching algorithm, we may have to make significant modifications in our original strategy. These issues will be addressed during CY 1997 with the goal of having a complete implementation strategy ready by the end of CY 1997.

(vi) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a method to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We will initiate a study to determine the efficacy of the present atmospheric correction algorithm on removal for the aerosol effect from the measurement of the fluorescence line height (MOD 20).

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(vi) We will examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing our out-of-band correction to MODIS.

b. Work Accomplished:

(i) We consider this task to be our most important atmospheric correction activity of 1997, and as such the major part of our effort on atmospheric correction will be focussed on it. During this CY, we have further tested our spectral matching algorithm that, although very slow, is capable of distinguishing between weakly- and strongly-absorbing aerosols. It is based on combining a model of the atmosphere with a water-leaving radiance model for the ocean, and effecting a variation of the relevant parameters until a satisfactory fit to the MODIS top-of-atmosphere radiance is achieved. In simulations it showed significant success in detecting the absorption properties of the aerosol, i.e., distinguishing between weakly- and strongly-absorbing aerosols. We demonstrated that, at least in the first approximation, it is also capable of functioning in the same manner when aerosol vertical structure is added as an additional parameter. (Note that vertical structure is only important when the aerosol is strongly absorbing.) We found ways to significantly increase the speed of the algorithm, and to enable it to operate using the same set of lookup tables that the basic algorithm uses. This will enable us to incorporate the spectral matching algorithm in the basic correction algorithm, to be called each $N \times N$ pixels (where $N \sim 10 - 100$) to insure that candidate aerosol models with the correct properties are being used by the basic algorithm. A complete report describing our progress on this task is provided in Appendix 1. Our goal is to be able to have this new algorithm functional by the end of this CY.

(ii) Some imagery has been acquired from the OCTS and we are preparing to test the performance of the algorithm in its present state.

(iii) None. This task has been put on hold to free resources for examination of task (i).

(iv) No work was carried out on this task.

(v) To study the efficacy of atmospheric correction of the fluorescence line height, we needed a set of lookup tables specific to the relevant spectral bands. These required about 14,000 radiative transfer simulations. These tables have been prepared for our basic aerosol models.

(vi) No work was carried out on this task.

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(vii) The specifics on incorporating the out-of-band corrections in the MODIS algorithm have been worked out.

c. Data/Analysis/Interpretation: See item b above.

d. Anticipated Future Actions:

(i) We will continue work on the spectral matching algorithm. Of particular interest is to devise a way of performing the optimization that is more efficient and accurate than the “brute-force” method described in Appendix 1. Also, we need to know how closely the candidate aerosol models must be to the true aerosol in order to effect a good retrieval. To try to understand this we are attempting to use generic power-law size distributions of identical particles (a size-independent refractive index) as candidates for retrieving aerosol and ocean properties when the true aerosol is a combination of two log-normal distributions with the two components composed of different species. The initial results for this have been encouraging.

(ii) As more OCTS imagery is acquired, we shall continue testing the algorithm. In particular, we want to test the spectral matching algorithm with real ocean color data.

(iii) None. The cirrus cloud issue in the presence of our spectral matching method needs to be explored. We will resolve the spectral matching questions first, then devise a strategy to implement the cirrus correction.

(iv) None.

(v) We will perform a basic test of the efficacy of the correction algorithm for retrieving the fluorescence line height.

(vi) None.

(vii) None, until we are provided with the final MODIS spectral response functions.

f. Publications: Four papers are in various stages of the publication process. They are:

H.R. Gordon, T. Zhang, F. He, and K. Ding, Effects of stratospheric aerosols and thin cirrus clouds on atmospheric correction of ocean color imagery: Simulations, *Applied Optics*, 36, 682–697 (1997).

H.R. Gordon, Atmospheric Correction of Ocean Color Imagery in the Earth Observing System Era, *Jour. Geophys. Res.* (In Press).

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H. Yang and H.R. Gordon, Remote sensing of ocean color: Assessment of the water-leaving radiance bidirectional effects on the atmospheric diffuse transmittance, ***Applied Optics*** (Accepted).

H.R. Gordon, T. Du, and T. Zhang, Remote sensing ocean color and aerosol properties: resolving the issue of aerosol absorption, ***Applied Optics*** (Accepted).

2. Whitecap Correction Algorithm (with K.J. Voss).

As the basic objectives of this task have been realized, work is being suspended until the validation phase, except insofar as the radiometer will be operated at sea when sufficient number of personnel are available. Karl Moore, the post doctoral associate who was responsible for the operation of the instrument and the data analysis, has moved to the Scripps Institution of Oceanography. In his absence our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract.

a. Task Objectives:

Operate the radiometer at sea to maintain experience in preparation for the validation phase.

b. Work Accomplished:

The radiometer was operated during a February cruise with Dennis Clark off Hawaii. From the standpoint of whitecaps this was a very good cruise (high winds). A large amount of whitecap data was collected.

c. Data/Analysis/Interpretation

At this time we have reduced the calibration data, but not the cruise data.

d. Anticipated Future Actions:

We will work to reduce the cruise data during this period, but it is a lower priority than the analysis of other data collected during this cruise.

e. Problems/Corrective Actions: None

f. Publications: Two papers on our whitecap work are still in the review process. They are:

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflectance of whitecaps: Instrumentation, calibration, and performance in coastal waters, *Jour. Atmos. Ocean. Tech.* (Submitted).

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflectance of whitecaps: Fractional coverage and the augmented spectral reflect ante contribution to the water-leaving radiance, *Jour. Geophys. Res.* (Submitted).

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3. In-water Radiance Distribution (with K.J. Voss).

a. Task Objectives:

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle.

b. Work accomplished:

The instrument failed just before use on a cruise in February. It was repaired and used during a short cruise in Florida Bay during May. On this cruise we obtained several upwelling radiance distributions in turbid Case 2 water. The instrument operated properly and was calibrated both before and after this cruise.

c. Data/Analysis/Interpretation: None.

d. Anticipated future actions:

We will operate this instrument during a cruise with Dennis Clark in July in Hawaii. We will also be reducing data from three cruises and their associated calibrations.

e. Problems/Corrective actions: None.

f. Publications: None.

4. Residual Instrument Polarization.

The basic question here is: if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction, and how can we correct for these effects?

a. Task Objectives:

Add a module to perform the correction for residual instrument polarization.

b. Work Accomplished:

A module was added to perform the correction for residual instrument polarization.

c. Data/Analysis/Interpretation: None.

d. Anticipated Future Actions:

Although this task is now basically complete. All that remains is incorporating the SBRS/MCST polarization-sensitivity data into the module.

e. Problems/Corrective Actions: None

f. Publications: The paper describing the polarization-sensitivity correction has been accepted for publication in *Applied Optics*.

H.R. Gordon, T. Du, and T. Zhang, Atmospheric correction of ocean color sensors: Analysis of the effects of residual instrument polarization sensitivity y, *Applied Optics* (Accepted).

5. Pre-launch/Post-launch Atmospheric Correction Validation (with K.J. Voss).

a. Task Objectives:

The long-term objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the ocean in order to verify the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this requires obtaining long-term time series in typical maritime environments. This will be achieved using a CIMEL sun/sky radiometer that can be operated in a remote environment and send data back to the laboratory via a satellite link. These are similar the radiometers used by B. Holben in the AERONET Network.

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation cannot be used (due to the motion of the ship) for this purpose. The required instrumentation consists of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer. We had a suitable sky camera and sun photometer but had to construct an aureole camera. Our objective for this calendar year is to make measurements at sea with this instrumentation, both to collect a varied data set and to test the instrumentation and data reduction procedures.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises. This can be accomplished with ship-borne LIDAR. We have procured a Micro Pulse Lidar (MPL) system and modified it for ship operation. Our goal during this reporting period was to successfully operate it on a ship.

(iii) The third objective is to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This requires a critical examination of the effect of radiative transfer on "vicarious" calibration exercises.

(iv) The fourth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, MSX), or are expected to achieve orbit (SeaWiFS) prior to the launch of MODIS, to validate and fine-tune the correction algorithm.

b. Work Accomplished:

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(i) During the last year we were operating the CIMEL in its location in the Dry Tortugas. In October this instrument was removed for recalibration. At the same time the AERONET network, run by B. Hobren, decided to upgrade the CIMEL instruments with more stable interference filters and small hardware changes. It was returned in June, just before we had the deployment for ACE-11. An attempt was made to install it in the short time before ACE-II; however it was unsuccessful as the instrument failed. It has been sent back to NASA and either they or we will install it during the next reporting period.

(ii) The sky camera system and aureole system was used on a cruise with Dennis Clark off of Hawaii (during February). Dennis Clark's group provided the sun photometer data. In addition to participating on the cruise we performed calibration of all the systems pre- and post-cruise. We have begun reducing sky radiance data obtained during several cruises in the last year. We have also reduced the aureole data from the first two cruises, and are currently evaluating this data. We are working on the data reduction procedures to allow measurements to be reduced in almost real time (each night) so that almucantor and principal plane measurements can be obtained quickly.

To try to extend the data base of aerosol optical properties, we examined the possibility of extending our sky radiance inversion algorithm for application over the land. The rationale for this is the simplicity of land-based compared to ship-based measurements in coastal areas. The results, as expected, show that as long as the land albedo is small, good inversions can be obtained in the red and near infrared regions of the spectrum. The complete results of this study are provided in Appendix 2.

To address the problem of vertical distribution of aerosols we have acquired a Micro Pulse Lidar from SSEI. We have constructed an air-conditioned weather-proof box for the instrument and this system was used for the first time during the February cruise with Dennis Clark. It performed well during this test, but a couple of modifications to its operation are being performed now. In particular the computer supplied with the system has had problems. These have been solved. We have made the following modifications to the MPL system to improve the reliability:

- Added tilted front window to the case to allow water to run off more easily and avoid retroreflect ion problems.
- Adding access panels to the Lidar box to enable us to check cabling and other system problems more easily.

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- Replaced the computer supplied by SSEI with a notebook computer to allow more reliable operation. This will also significantly reduce the shipping costs required for the system.

(iii) We have completed a study of the accuracy with which one can compute the radiance at the top of the atmosphere from sky radiance measurements made at the sea surface. The results suggest that the bulk of the error is governed by the uncertainty in the sky radiance measurements. Furthermore, as it was shown that the largest error in the radiative transfer process was the error due to the use of scalar radiative transfer theory, we developed an inversion/prediction method using vector theory. We find that it is possible to predict the polarization state of the top-of-atmosphere radiance quite accurately from surface measurements. This may be very important for validating the pre-launch polarization-sensitivity characterization of MODIS.

We completed definition of the requirements for the vicarious calibration of ocean color sensors in general. This has been submitted for publication and is included here as Appendix 3.

(iv) We have obtained small quantities of OCTS data and are working with R. Evans to test the MODIS algorithm with these data.

c. Data/Analysis/Interpretation:

(i) Since August 1993 we have been making aerosol optical depth measurements at three sites occupied by the Atmosphere/Ocean Chemistry Experiment (AEROCE) in Miami, Bermuda, and Barbados. Analysis of this data is complete. A draft paper describing the results of this analysis is provided here in Appendix 4.

(ii) We have described the design and operation of our sky camera (with the polarization feature) in two publications submitted to *Applied Optics*. These papers also provide samples of data acquired at Miami. They are included here as Appendices 5 and 6.

In addition, we have begun processing the MPL data from the February cruise. As an example we show two figures. Figure 1 shows the MPL return as a function of time between 0300 and 0400 GMT on February 25, 1997. In this figure the major aerosol is low, between 0 and 1 km. Between 1 and 2 kilometers some fairly thin clouds appear and disappear through the night. Figure 2 is an inverted LIDAR return. This is from the 6th minute of the hour shown in the time series. Obvious in this graph is the higher aerosol near the surface, falling off to 1 km, where a thin cloud appears (1-2 km). The signal very near the surface (0-200 m) is not available because of the instrument

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self return. We are still learning how to process the data from the LIDAR, and will look at the data collected during the February cruise and ACE-II during the next reporting period.

d. Anticipated Future Actions:

(i) We will be reinstalling the CIMEL in the Dry Tortugas at the first opportunity after its return from NASA. We are also working on a better method of acquiring the data through NASA. This will enable us to look at the sky radiance data in a more timely manner.

(ii) We will finish the data reduction work with the sky camera system in the next reporting period. We are also reworking portions of this system to allow more automation of the data collection, and fix minor problems which developed during the last cruise (specifically overheating of the system computer and corrosion on the computer backplane). The reduced aureole data will be merged with the sky radiance data to provide a complete sky radiance distribution during this next period. We will also finish reducing all of the aureole data, and we will use the sky camera and aureole camera during a cruise in July with Dennis Clark.

Much effort in this reporting period has gone toward getting ready to deploy the MPL in Tenerife, Canary Islands during ACE-II. This will occur during June and July and will give us a chance to collect Lidar profiles along with CIMEL sun/sky radiometry and atmospheric chemistry measurements from airplanes, surface and ships. In addition, another MPL is being deployed by Dr. John Reagen at Univ. of Arizona so that simultaneous measurements will be obtained at the surface, near the ocean, and at Izania, a mountain observatory. This data set should help us determine the vertical structure of dust as it comes off of the Sahara. African Dust is an important absorbing aerosol over the Atlantic. One goal of this work for 1997 is to begin obtaining a data base of the thickness of the Saharan dust layer over the Tropical Atlantic.

(iii) We *will* apply our sky radiance inversion algorithm to actual data obtained at sea.

(iv) We will continue working with R. Evans on implementation of our atmospheric correction algorithm on our R10000 computer to facilitate tie-tuning the algorithm.

e. Problems/corrective actions: None.

MPL Signal Return on February 25, 1997 (0300 GMT)

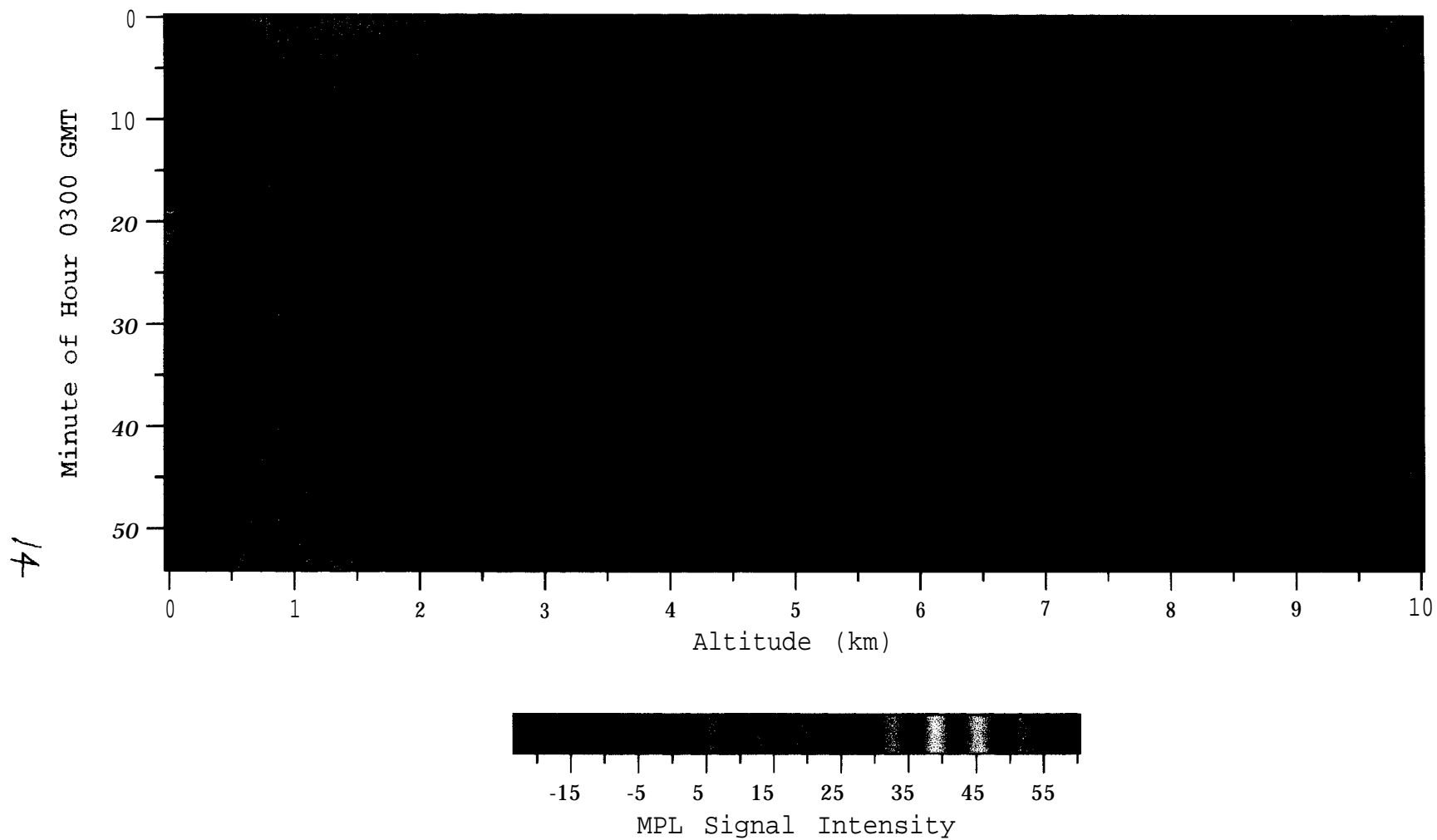
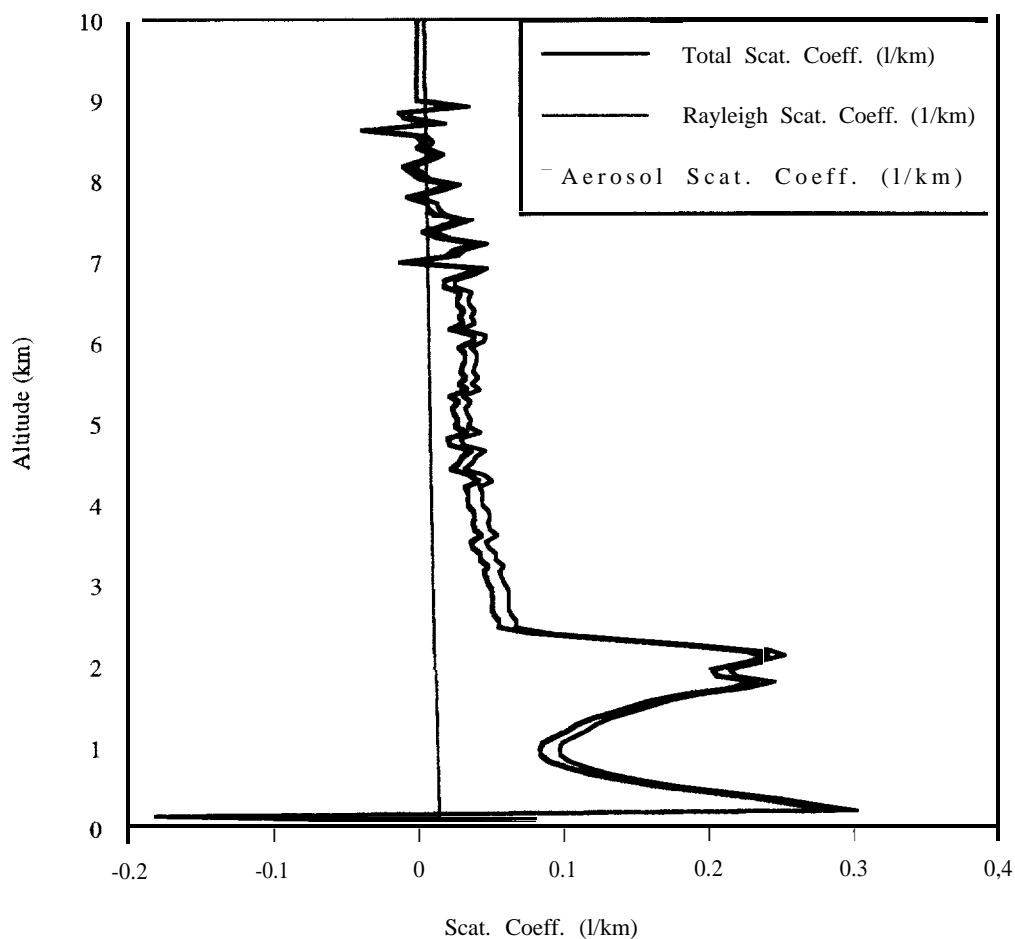


Fig 1

MPL Scattering Coeff. February 25, 1997 (0300 GMT)



```
(NasaHeader) unit_number: 50
Record Number 12
month: 2 day: 25 year: 97
hour 3 minute: 6 second: 20 hund_sec: 0
trigger_freq: 2500
energy_monitor: 6.199000
detect_temp: 25.890000
filter_temp: 0.000000
box_temp: 22.260000
laser_temp: 24.790000
ten_volt: 0.000000
five_volt: 0.000000
fifteen_volt: 0.000000
cbh: 0.000000
background: 0.318874
bintime: 500.000000
maxaltitude: 30.000000
deadtimecorrected: 0.000000
altitudeInt: 0.075000
numberBins: 400.000000
averageTime: 30.000000
numberRecords: 109.000000
```

Fig 2

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f. Publications: Several papers in various stages of the publication process are listed below.

D.K. Clark, H.R. Gordon, K.J. Voss, Y. Ge, W. Broenkow, and C. Trees, Validation of Atmospheric Correction over the Oceans, *Jour. Geophys. Res.* (In press).

K.J. Voss and Y. Liu, Polarized radiance distribution measurements of skylight: Part 1, system description and characterization, *Applied Optics* (Accepted).

Y. Liu and K.J. Voss, Polarized radiance distribution measurements of skylight: Part 2, experiment and data, *Applied Optics* (Accepted).

H. Yang and H.R. Gordon, Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over Land: Simulations, *Applied Optics* (Submitted).

H.R. Gordon, In-orbit calibration strategy of ocean color sensors, *Remote Sensing of Environment* (Submitted).

6. Detached Coccolith Algorithm and Post Launch Studies (W.M. Balch).

a. Task Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, *E. huxleyi* is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focussed on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scatter, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this reporting period months have been:

- (1) Acquire optical field data on the distribution and abundance of coccolithophores in the Gulf of Maine.
- (2) Summarize our flow cytometer experiments for publication.
- (3) Publish earlier results from a 0.5 million square kilometer coccolithophore bloom.

For perspective on the directions of our work, we provide an overview of our previous activities. During 1995, we focussed on chemostat cultures (in which algal growth rate was precisely controlled) and we examined how the optical properties of these calcifying algae changed as a function of growth. During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian sea, measuring coccolithophore abundance, production, and optical properties. During the first half of 1996, we focused again on field calcite distributions, during two Gulf of Maine cruises, one in March and one in June. During the second half of 1996, we participated on another cruise to the Gulf of Maine.

b. Work Accomplished:

1) We have processed samples for calcification rates and chlorophyll concentrations from our November 1996 Gulf of Maine cruise. We sampled for total and calcite-dependent backscattering (continuously), suspended calcite concentrations, calcification rates, chlorophyll concentrations, coccolithophore and coccolith counts, and particulate organic carbon. The microscope work is still ongoing.

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2) We installed a new Argon-Ion laser in our Wyatt light scattering photometer and successfully re-calibrated the instrument. The new laser will provide us with 514 nm wavelength light which is more appropriate for the coccolithophore work.

3) We performed a pre-launch MODIS cruise in the Gulf of Maine aboard the RV Albatross under extremely bad weather conditions (up to 50 kt winds and 20 foot seas). We ran our underway system for the entire trip (~ 1500 nautical miles) without a problem. On this cruise, we provided sea truth radiance and irradiance data for the OCTS (with imagery coordinated with Dr. Gene Feldman). We visited 60 stations, 28 of which were full optical stations (with measurements of total backscattering, acid-labile backscattering, calcite concentrations, coccolithophore and coccolith counts). We had the Yentsch/Phinney group on board measuring spectral absorption, in situ absorption/attenuation (AC-9), upwelling and downwelling irradiance (SATLANTIC TSRB bio-optical sampler), dissolved organic matter absorption, and in situ backscattering (performed by Dr. Ajit Subramanian).

4) Suspended calcite samples from the Gulf of Maine have been run in the graphite furnace atomic absorption spectrometer at the University of Maine. We now only have samples from our most recent cruise in June '97.

5) All cell and coccolith counts from the Arabian Sea were completed and the data from process cruise 6 are being entered into spreadsheets at this time. We now are focussing on the several hundred cell count samples from our recent Gulf of Maine cruises. This will take many months to complete.

6) All calcification data from the March, June and November 1996 Gulf of Maine cruise have been processed to units of $\text{gC m}^{-3} \text{d}^{-1}$ and integrated over the water column at each station. They have been processed into complete sections.

c. Data/Analysis/Interpretation:

Single cell experiments

We have focussed on data analysis for our flow cytometer experiments. This work has entailed the processing of backscattering coefficients of 8 species of calcifying algae, plated-with or denuded-of coccoliths. We also sorted detached coccoliths of these different species for bulk analysis. Following measurements, the calcite was measured using graphite furnace atomic absorption spectrometry. These samples were run during the preceding 6 months at the University of Maine Darling Center. The other aspect of this work was to sort calcite particles from field samples, and

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to measure their scattering and calcite composition. The atomic absorption samples, too, were processed in the last 6 months.

One of the interesting aspects of the flow cytometer analysis was comparing backscattering by particulate inorganic and organic matter to data by Morel. The results of organic carbon scattering shows strikingly good agreement with Morel's data. The consistent organic carbon results allow us to estimate both inorganic and organic carbon standing stock using our flow-through scattering detector. The first draft of a manuscript has been written which summarizes these results.

Cruise results

Calcite-dependent backscattering was quite high in the Gulf Maine during June, 1997; chlorophyll levels were moderate. Calcite scattering commonly accounted for 10-20% of total backscattering. Interestingly, it was highest over Georges Bank and in coastal waters as opposed to Wilkinson Basin, a stratified basin in the middle of the Gulf of Maine. The underway data from the Gulf of Maine are being merged with our calibration measurements (calibrations are periodically made at sea and these data are being processed to verify instrument calibrations). Hydrographic plots of the Gulf of Maine data will be made in which light scattering and chlorophyll are plotted in temperature salinity space.

The March, June and November cruises to the Gulf of Maine were processed to show the aerial distribution and depth profiles of calcification. Interestingly, these results showed that the shelf waters near the tip of Cape Cod to be a "hot spot" for calcification. We have observed this before. Georges Bank also had higher-than-expected calcite concentrations in June.

d. Anticipated Future Actions:

Work in the next year will address several areas:

- 1) Processing of the suspended calcite samples from the June '97 cruise,
- 2) Final analysis and write-up of our fall flow cytometer experiments.
- 3) Continued microscope cell/coccolith counts for samples from the Gulf of Maine.
- 4) We will go to sea in November on another Gulf of Maine cruise.

e. Problems/Corrective Actions: None

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f. Publications: During this time reporting period, two papers have been revised for publication. One dealing exclusively with the optics coccolithophores is included here as Appendix 7.

Voss, K., W. M. Balch, and K. A. Kilpatrick. Scattering and attenuation properties of *Emiliana huxleyi* cells and their detached coccoliths. Revised for *Limnol. Oceanogr.*

Balch, W. M. and B. Bowler. Sea surface temperature gradients, baroclinicity, and vegetation gradients in the sea. In revision for *J. Plank. Res.*

7. Other Activities.

The PI participated in the MOCEAN meeting in Miami in January, and met with A. Fleig and K. Yang of SDST regarding MODIS Ocean test data sets. The PI worked with MCST and SBRS to resolve the issue of proper measurement of the MODIS polarization sensitivity. The issue was successfully concluded in early May. The PI participated in the MODIS Science Team meeting in May, and reviewed the MS CT Level-1B processing algorithms.

Several papers were presented at the AGU Spring Meeting in Baltimore. They are provided below.

H. Yang and H.R. Gordon, Retrieval of aerosol properties over land, *EOS, Transactions, AGU*, S70 (1997).

E.J. Welton, K.J. Voss, and J.M. Prospero, Radiative characteristics of specific types and concentration of aerosols in the marine environment, *EOS, Transactions, AGU*, S88 (1997).

J.M. Ritter, K.J. Voss, and H.R. Gordon, A new instrument for shipborne radiometric measurements of the solar aureole, *EOS, Transactions, AGU*, S93 (1997).

8. Appendices

- 1.** H.R. Gordon, T. Du, and T. Zhang, Remote sensing ocean color and aerosol properties: resolving the issue of aerosol absorption.
- 2.** H. Yang and H.R. Gordon, Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over Land: Simulations.
- 3.** H.R. Gordon, In-orbit calibration strategy for ocean color sensors.
- 4.** E.J. Welton, K.J. Voss, and J.M. Prospero, Long term aerosol optical depth analysis, Program description and results (DRAFT).
- 5.** K.J. Voss and Y. Liu, Polarized radiance distribution measurements of skylight: Part 1, system description and characterization.
- 6.** Y. Liu and K.J. Voss, Polarized radiance distribution measurements of skylight: Part 2, experiment and data.
- 7.** Voss, K., W. M. Balch, and K. A. Kilpatrick. Scattering and attenuation properties of *Emiliania huxleyi* cells and their detached coccoliths.